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some unusual twin-laws observed in the orthoclase crystals from Goodsprings, Nevada.

(With Plate I.)

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[Read June 25, 1936.]

HE very abundant literature dealing with the twinning of felspar henocrysts has put on record a surprisingly large number of twin- Some of these have such complex indices that they have never accepted; others are regarded as doubtful. Yet the authors of have well-established reputations and the accuracy of their vations cannot be doubted.[1] The difficulty lies in the interpreta- of the results. Beside numerous examples of well-defined laws, omes across a high percentage of isolated cases, each appearing as plausible as these, yet difficult to assign to any definite law. Klockmann[2] gave a number of suggestions for their explanation, on the superposition of similar angles in different zones. This was expanded by G. Tschermak[3] and by H. Baumhauer.[4] These y geometrical considerations gave rise to the notion of 'hetero- nge' and 'zweiachsige Verwachsungen' which, instead of clearing oubtful points, has only succeeded in introducing confusion. ola[5] continues, however, in the same direction and these conclusions ccepted and utilized by petrographers, for whom the identification in-laws of the felspars serve in the determination of igneous rocks.

r example: H. Laspeyres, Zeits. Kryst. Min., 1877, vol. 1, p. 346; W. Müller, 890, vol. 17, p. 484; F. Gonnard, Bull. Soc. Min. France, 1883, vol. 6, p. 265; ier, ibid., 1909, vol. 32, p. 155.

Klockmann, Zeits. Kryst. Min., 1882, vol. 6, p. 318.

Tschermak, Min. Petr. Mitt., 1879, vol. 2, p. 499; 1887, vol. 8, p. 414.

Baumhauer, Zeits. Kryst. Min., 1899, vol. 31, p. 252.

Viola, Zeits. Kryst. Min., 1900, vol. 32, pp. 309–337; 1902, vol. 36, p. 234.

The lists of recognized 'felspar twins' given by them are based on the identification, by optical methods, of the mutual orientations of crystals found in juxtaposition in a thin section. The more cautious recognize, in many of these, the results of the *association* of several laws. E. S. Fedorov and W. Nikitin,[1] to mention one instance, still retain the double name 'Albite-Carlsbad' for one such association, while C. Viola gives it the name of the 'Scopi law'. V. Goldschmidt and R. Schröder[2] have proposed a number of such 'laws' based on purely geometrical juxtapositions. On the other hand, R. Sabot[3] classes one quite normal law, the Petschau law with twin-axis [1$\bar{1}$0], among the associations of several laws.

The author was led to consult this literature when studying the twin-laws of the andesine phenocrysts from the Esterel 'blue porphyry'.[4] His object was to identify or obtain confirmation for some isolated cases or complex associations. He found that, before this could be done successfully, it would be necessary to determine, by more detailed examination of more convincing material, which laws were really well established. As a beginning in this direction, it seemed advisable to examine the cases of orthoclase twinning, for it is for this monoclinic felspar that the largest number of rather doubtful laws have been proposed. The results could, later, be extended to the plagioclases.

While in search of suitable material, the opportunity was given of studying a few orthoclase phenocrysts collected some time previously by Dr. W. F. Foshag, of Washington, at Crystal Pass, Goodsprings, Nevada. The author wishes to express here his best thanks to Dr. Foshag for this opportunity. Further material from this same locality was offered by Messrs. A. Montgomery and E. Over, two very keen American mineral collectors, and about a hundred specimens were received from them. This material seemed so ideal for the purpose that arrangements were made with Messrs. Montgomery and Over to collect a larger supply. In this they were very successful. They collected separately the whole of the phenocrysts from one large mass of rock, so that a quantitative estimate of frequencies could be made. Then they collected all the less common varieties from another large mass, to obtain plenty of useful material without being overloaded with excess

[1] E. S. Fedorov and W. Nikitin, quoted by R. Sabot, loc. cit., 1922, p. 110.

[2] V. Goldschmidt and R. Schröder, Beitr. Kryst. Min., 1923, vol. 2, p. 118. [Min. Abstr. **3**–213.]

[3] R. Sabot, Bull. Soc. Franç. Min., 1922, vol. 45, p. 97. [M.A. **2**–347.]

[4] J. Drugman, Bull. Soc. Franç. Min., 1925, vol. 48, p. 254. [M.A. **3**–380.]

e more ordinary cases. Broken material was discarded, but break- seemed to be spread fairly uniformly over the different types, gh, perhaps, Manebach twins, that separate easily along the com- ion-plane (001), may be underestimated as, also, some more fragile plex groups. The estimate is a rough one, but it gives a fair idea of relative frequencies of well-developed twins. The following figures obtained:—

Untwinned crystals	1830
Carlsbad twins	530
Baveno twins	60
Manebach twins...	60
Other twin-laws and complexes	195
Total	2675

more detailed subdivision will be given farther on, in which will cluded less obvious cases of twinning removed, after closer examina- from the 'untwinned' or 'Carlsbad' cases in the above estimate. y cases will also be added where several laws are found side by side he same specimen. The second lot of material yielded 135 picked imens showing rare or complex associations. In spite of the high ity of the material and of its abundance, the object of this note was partially attained, the same difficulties arising in the interpretation olated cases.

e rock is described as a much weathered granite-porphyry occurring ike-like masses. Most of the crystals are pink or orange-red, some red, and others snow-white. These last seem to be completely ed, as is the rock in which they occur. Some crystals are fairly fresh, -coloured, and translucent. The phenocrysts are sharp and clean- their habit simple and very constant. A large proportion only (001), (010), and (110) in approximately equal development (pl. 1,). The ($\bar{2}01$) faces are very subordinate and often absent; (021),), and (130) are only occasionally met with. In normal-typed Mane- twins, however, faces ($\bar{2}01$) or ($\bar{1}11$) are well developed at the lower emity.

ontgomery and Over noticed a number of much-rounded crystals se edges were almost invariably bevelled by ($\bar{1}11$), (021), and (130), supposed they had been derived from a special portion of rock. y, however, found a specimen on which the clean-cut and rounded s were embedded side by side. The rock has more the texture of ff, and these two varieties of crystals were probably enclosed in it n already formed.

From the first, wide divergencies were observed in the angles of some of the rarer cases that seemed, otherwise, to be of the same nature, and the publication of this note has in consequence been delayed. But similar divergencies were observed in cases that were undoubted Carlsbad or Baveno twins and even between the different elements of parallel growths. The specimens were, therefore, carefully selected and only those that seemed to be the most free from serious deviations were utilized. These deviations, which have been already recorded from other felspar localities, are probably due to pressure and strain in the rock.

The habit of the Goodsprings crystals is such a typical one and the variants from the normal type, of certain laws, so unusual that a photographic plate (pl. 1) seemed the best means of rendering them. The line-drawings on the same scale on the transparent overlay explain these. The reproductions show the natural size of the crystals.

A. *Carlsbad law twins.*—Unlike Carlsbad twins from other localities, the habit of the constituent crystals is almost unchanged (pl. 1, fig. 2*a*). There is little, if any, flattening on (010) and the elongation parallel to the *c*-axis is only observed in about half the number of Carlsbad twins. A second type is frequent (pl. 1, fig. 2*b*) in which one crystal is predominant, the second emerging from a (001) face of the larger. This variety was frequently met with in the Esterel andesines. In these, the habit of the simple crystal remains generally quite unchanged. The more symmetric type of Carlsbad twin, when elongated in the direction of the *c*-axis, has a marked pseudo-hexagonal aspect.

B. *Manebach law twins.*—Two types are met with: a 'normal' type, elongated in the direction of the *a*-axis; and an undistorted type that can be termed the 'short type' of Manebach twin.

(1) *Normal type.*—The twin-plane is well-defined as composition-plane and the lower end is modified by the secondary forms generally observed in Manebach twins from other localities. The predominance of $(\bar{2}01)$ gives rise to a 'blunt' lower termination (pl. 1, fig. 3*a*), whereas the predominance of $(\bar{1}11)$ leads to a 'bipointed' variety (pl. 1, fig. 3*b*) in which the lower four-faced point is decidedly more acute than the upper one formed, invariably, of four (110) faces.

(2) *Short type Manebach twins.*—This type has already been observed in American orthoclases. The simple crystals retain their habit unaltered and there is no elongation parallel to the *a*-axis. Four (110) faces form the upper point and their parallels form a very pronounced re-entrant angle at the other end (pl. 1, fig. 5). The two crystals interpenetrate and

often show complex interlocking at the upper points. The influence of twin-plane seems, here, very subordinate and there is no visible composition-plane parallel to (001).

Between these two types, a number of interesting intermediate cases occur, most of them appearing to have originated in a normal-type twin. In these 'variants' the lower end always remains symmetric and may show either blunt or pointed terminations. At this end a composition-plane is quite obvious. But the upper end assumes more and more the characteristics of the short type. The upper ends interlock and one crystal is often prolonged much beyond the other (pl. 1, fig. 4*a*) and often takes up the whole width, 'capping' the other (pl. 1, fig. 4*b*). It would be interesting to investigate the reasons for this different behaviour at the two ends. The twin-plane seems to fill an essential role in the normal, long type, but not in the short type. A twin-axis is probably the dominant factor in the latter.[1] Whatever this factor is, it is a very local one, as is proved by one very interesting specimen. In this specimen, a long type and a short type Manebach twin are seen intercrossing in Carlsbad twinning (pl. 1, fig. 6). Each type retains its characteristics in this complex, in spite of the intergrowth of the two.

C. *Baveno law twins.*—There is more uniformity in the development of the Baveno twins from Goodsprings, yet two types can be observed, showing similar differences. A normal type shows some elongation along the edge (001)/(010). It has a composition-plane roughly parallel to the twin-plane and no obvious re-entrant angles (pl. 1, fig. 7).

The second type can, here too, be termed the 'short' type and is formed of unchanged simple crystals that interpenetrate with very obvious re-entrant angles (pl. 1, figs. 8*a* and *b*). In some of these, the two crystals are sometimes joined end-on. There is no definite composition-plane.

D. *Twinning on face* (110) *and on face* (130).—A number of laws with twin-plane in the prism-zone have been described. But the only well-established ones are twinning on (110) and on (130). Examination of the Goodsprings material confirms this, though a few isolated specimens suggest the possible existence of other laws. These would, theoretically too, be much less probable.

Quite a number of twins on (110) have been identified in this material, three very symmetric ones being shown on the plate (pl. 1, figs. 14*a*, *b*, *c*). Figs. 14*a* and *c* are shown in plan and 14*b* in elevation. Two or three

[1] Cf. G. Friedel, Étude sur les groupements cristallins. Bull. Soc. Indust. Minière, Saint-Étienne, 1904, ser. 4, vols. 3–4, p. 160.

twins on (130) have been identified, but this seems a less frequent aw than twinning on (110).

E. *Twinning on faces in zone* [010].—When this note was read before the Society in June 1936, two specimens (nos. 109 and 110) were exhibited that seemed to point to the existence of twinning on ($\bar{3}02$). A third, whose inclination of the *c*-axes differed rather widely from that of these two, was very like them in all other respects, so much so that, when hastily putting together a set of specimens to show at the meeting, it was included with these two. A more detailed examination of the material yielded a number of other specimens having in common the parallelism of the (010) faces, yet having different inclinations of the *c*-axes. It is in this zone that the twin-laws with the most improbable indices have been suggested in earlier literature. It seemed, therefore, doubly important that all doubtful cases in this zone should be examined with care.

Of the cases with parallel *b*-axes, a few were peculiar in that they could not be explained by a single operation, either rotation about an axis or reflection on a plane, whereas a 'tilt forward' of the *c*-axis of one crystal in the plane (010) would explain them. One was soon identified as an association of Carlsbad with Manebach twinning; it was, in fact, an example of the 'Carlsbad-Manebach' association, already observed in the andesines from the Esterel, in which the middle crystal, of the three associated together and acting as link to the two outer ones, was not visible. It was more than likely, therefore, that the other examples characterized by a 'tilt' forward of one crystal were also complex associations of these same two laws.

An examination of all the cases having (010) parallel showed that each of them could be explained by repeated association of these two laws, and that, at the same time, some of the most improbable of the laws with very complex indices could also be explained quite rationally by this same process. So as not to expand the explanation of each case unduly, the results arrived at are given in the form of a table (see opposite page).

The association of the Carlsbad and Manebach laws is frequent, so that association A is well established as a *limiting-case*, in which the middle crystal is masked by excessive development of the two outer ones. Each additional element makes the corresponding case less probable. But the frequency of the occurrence of the Manebach and Carlsbad laws is such that these more complex associations become quite possible. It is only a question of great abundance of material for such to come to light, as has been the case in this Goodsprings occurrence.

Nature of assoc. C = Carlsbad M = Manebach.	Angle between *c*-axes.	Angle between (001) faces.	Observations.
C–M 1–2–3	'tilt' of 52° 6′	127° 54′ (−52° 6′)	Nos. 352 and 353 from Goodsprings; Des Cloizeaux's Emfola law, with proposed twin-plane ($\bar{4}03$).[1]
C–M–C 1–2–3–4	52° 6′	75° 48′	Not observed at Goodsprings; probably Gonnard's supposed twin on (15.0.4).[2]
M–C–M 1–2–3–4	104° 12′	52° 6′	Nos. 109 and 110 from Goodsprings; Vigier's supposed-'macle de St. Yvoine' twin-plane ($\bar{7}$.0.11).[3]
C–M–C–M 1–2–3–4–5	'tilt' of 104° 12′	104° 12′	No. 111 from Goodsprings.
C–M–C–M–C 1–2–3–4–5–6	104° 12′	156° 18′ (−23° 42′)	Nos. 235, 352, 477 from Goodsprings.
M–C–M–C–M 1–2–3–4–5–6	156° 18′	104° 12′	Nos. 351, 471, 542 from Goodsprings; Vigier's supposed 'macle no. 1', twin-plane ($\bar{1}$5.0.8).

The suggested laws with the very improbable indices ($\bar{4}03$), ($\bar{7}$.0.11), 5.0.4.), and ($\bar{1}\bar{5}$.0.8) can be considered as disproved. The name 'Emfola w' has been adopted in a number of memoirs, and may be retained, long as its true nature of association of the Carlsbad and Manebach ws be kept in mind.

F. *Twinning on a* (*hkl*) *face.*—A large number of very symmetric amples of twinning on some ($\bar{h}kl$) faces were observed in the Goodrings material. Both right- and left-handed varieties occur, that is, which either a ($\bar{h}kl$) or a ($\bar{h}\bar{k}l$) face is twin-plane. The type of these very uniform and the author suggests the term 'Goodsprings type' a distinguishing term for it. A number of the better developed ecimens gave measurements pointing to twinning on face ($\bar{1}$12) or ($\bar{1}\bar{1}$2) nd the name Goodsprings law had at first been retained for it. But easurements of other specimens varied within such wide limits that e law cannot be definitively confirmed. It is therefore better to retain e name, temporarily, for the type only. (Pl. 1, figs. 12*a* and *b*, and *b*′.)

[1] A. Des Cloizeaux, Manuel Min., 1862, pl. 25, fig. 149.

[2] F. Gonnard, Bull. Soc. Franç. Min., 1908, vol. 31, p. 286. While suggesting 5.0.4) as a possible twin-plane, he recognizes that the association can be explained two operations.

[3] A. Vigier, Bull. Soc. Franç. Min., 1909, vol. 32, pp. 155–170.

A number of laws have been mentioned in felspar literature with (*hkl*) faces as twin-plane. Twinning on ($\bar{1}11$) is the only one, however, that seemed so far to be well established. One single specimen from Goodsprings confirms it. The theoretical angles for the law are very close to those for another law that will be described below. Only relative importance can, therefore, be attributed to this confirmation. One other isolated specimen, very symmetric in its development, points to the possibility of twinning on (111). Confirmatory evidence is, however, still lacking for it.

Some forty other specimens, mostly isolated cases, have not been identified and must, unless shown later to belong to some definite law, be temporarily classed as chance intergrowths. Two modes of grouping occur, however, that are each represented by a number of specimens, yet cannot with certainty be attributed to a definite law. They will, temporarily, be mentioned as possible laws X and Y.

G. *Twinning about axis* [$\bar{1}12$]; 'Nevada law'.—One isolated specimen was shown, when this paper was read, that pointed very decidedly to the existence of a law with twin-axis [$\bar{1}12$]. At the time, no other specimen had been identified, but this one was so convincing that there was little doubt of its true twin nature (pl. 1, fig. 11). As this law is new, the name of 'Nevada law' is suggested for it. It has been conclusively confirmed by the discovery of twenty examples. The best-developed specimens show a marked pseudo-rhombohedral symmetry and a trigonal axis of twinning had first been looked for. But this supposition was not confirmed, measurements and the projections of these on a stereographic chart pointing conclusively to twinning about the axis [$\bar{1}12$], i.e. the edge between (110) and ($1\bar{1}1$). One prism face (110) is parallel in the two crystals, as all other faces in the zone [$110/1\bar{1}1$], namely ($0\bar{2}1$).

The example of twinning on ($\bar{1}11$), alluded to earlier, is very similar to the Nevada law twins; but, here, the ($\bar{1}11$) faces are strictly parallel, while there is a difference of several degrees in the Nevada law.

H. *Twinning about axis* [$1\bar{1}0$]; *Petschau law.*—This law was first observed by G. Tschermak at the Koppenstein, near Petschau, Bohemia.[1] It was confirmed, later, by V. Goldschmidt and F. E. Wright[2] and, more recently, by the author.[3] A number of examples were identified in the Goodsprings material, five at least being quite undoubtedly twins

[1] G. Tschermak, Min. Petr. Mitt., 1887, vol. 8, p. 414.

[2] V. Goldschmidt and F. E. Wright, Zeits. Kryst. Min., 1898, vol. 30, p. 300.

[3] J. Drugman, Bull. Soc. Franç. Min., 1928, vol. 51, p. 193. [M.A. 4–37.]

n the Petschau law. The angles of a number of other specimens differ, owever, and the lack of parallelism of the (110) and (001) faces of a ew is obvious. These seem to group themselves about two different neans, but no definite laws are, so far, discernible. These are the two ıws, or possible laws, temporarily termed the X and Y laws already lluded to.

It is the presence of such cases, that are not *quite* the same, that makes he study of orthoclase phenocrysts so difficult. The plausibility of ome is such that one is often tempted to assign fixed characteristics o them, whereas they may be due to external causes in no way related o twinning.

If G. Friedel's suggestion of the existence of 'monoperiodic' and diperiodic' twins holds,[1] and his arguments for their existence are well considered, we may find that many of these doubtful cases will fall nder one of these heads. A monoperiodic twin need only have the *irection* of one zone-axis in common, the other directing factors lacking. A well-developed face in such a zone would tend to fix the pair in some lefinite orientation, without actually being a twin-plane. A repetition of very similar cases would result, such as have been observed. It might e remarked that there would be little difference between these and heterozwillinge'. They are, however, based on one element of the attice, common to both crystals, whereas in a 'heterozwilling' two nlike elements of the lattice are made to coincide. This is a purely geometrical operation in which the spacings in the lattice are not considered and, thus, with no sound scientific basis.

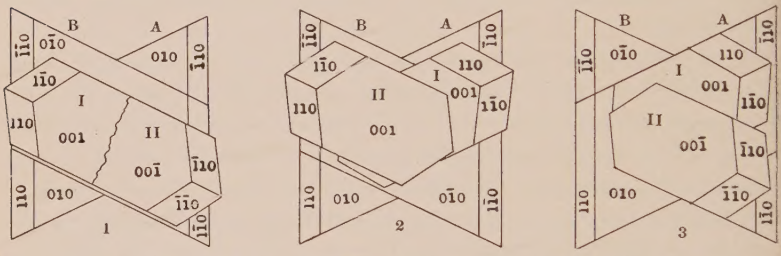
I. *Complex Associations.*—The conditions in which the phenocrysts of igneous rocks crystallize is very favourable to the formation of twins. There is, therefore, a tendency for these to be formed at all moments of growth of each crystal; hence the numerous cases in which several laws are observed on the same specimen. Their repetition gives rise to certain types that are so well defined, as we have already seen, that some have been treated as definite twins or 'heterozwillinge'. We will mention shortly the most frequent.

(*a*) The association of the Carlsbad and Manebach laws has already been described. It is the case observed by Des Cloizeaux from Cape Emfola, with the 'Carlsbad-Manebach association' as the limiting case. A further repetition of the same two laws gives complex groups, some of which had previously been described as twins with very high indices.

[1] G. Friedel, Bull. Soc. Franç. Min., 1933, vol. 56, p. 262. [M.A. 5–428.]

(*b*) Manebach twinning is often seen combined with Baveno twinning, though rare at Goodsprings.

(*c*) The association of the Carlsbad and Baveno laws is a very common one, both in orthoclase and some plagioclases (pl. 1, fig. 9*a*). The limiting case, the 'Carlsbad-Baveno association', is even more frequent than that still showing the three crystals (pl. 1, fig. 9*b*). Without defining it clearly, F. Gonnard shows it from Four-la-Brouque, while V. Goldschmidt and F. Paul[1] describe it as a 'heterozwilling', giving it the name of the 'Koppenstein law'.



Figs. 1–3. Baveno twins on Carlsbad twins of orthoclase.

Fig. 1. It winned on $(0\bar{2}1)$ of B; II on $(0\bar{2}\bar{1})$ of B.

Fig. 2. I twinned on (021) of A; II on $(0\bar{2}1)$ of B. Plane of symmetry bisecting the obtuse angle between the (010) faces of I and II.

Fig. 3. I twinned on (021) of A; II on $(0\bar{2}\bar{1})$ of B. Plane of symmetry bisecting the acute angle between the (010) faces of I and II.

(*d*) A 'Carlsbad with Carlsbad-Baveno association' is also observed fairly frequently at Goodsprings (pl. 1, fig. 10).

(*e*) 'Double Carlsbad-Baveno twinning', in which each of the Carlsbad pair has another crystal in Baveno twinning to it, also occurs, but is very rare. F. Gonnard mentions the possibility of a number of similar associations.

An example was found at Goodsprings in which Baveno twinning is repeated twice on the same crystal of a Carlsbad pair (text-fig. 1). One crystal is Baveno-twinned on the $(0\bar{2}1)$ face, the other on the $(0\bar{2}\bar{1})$ face. These two crystals, lying on the same (010) face of the larger crystal simulate an 'end-on' Manebach twin. This gives a possible explanation to a case described by Müller where very improbable indices have been suggested for the twin-plane.[2] Very abundant material yielded four 'stellate twins' having (001) in one plane and the (010) faces at 127° 49′

[1] V. Goldschmidt and F. Paul, Zeits. Kryst. Min., 1909, vol. 46, p. 471.

[2] W. Müller, Zeits. Kryst. Min., 1890, vol. 17, p. 484.

o each other. The accuracy is not stated, but we may assume that, n such rough crystals, measurements were only approximate. This is ose to the angle of the (001) faces of a Carlsbad twin. Baveno twinning peated on the Carlsbad pair would give a 'double Carlsbad-Baveno' ssemblage in all respects similar to Müller's specimens. Another eculiarity of Müller's specimens adds to the value of this new interpreta- on. Two of the four specimens have their ($\bar{2}01$) faces disposed sym- etrically about the obtuse angle between the (010) faces, the other wo symmetrically about the acute angle between the (010) faces. Müller had suggested a twin-plane ($\bar{8}63$). O. Mügge[1] suggested two ifferent twin-laws for the two cases, namely, twinning about an axis [130] and twinning about an axis [$\bar{1}30$]. These interpretations are just s improbable as Müller's, whereas the two groups are explained quite imply as repeated Carlsbad-Baveno associations (text-figs. 2 and 3).

(*f*) There is one more mode of grouping, occurring generally in the rm of a thin plate, with its (010) face resting on the (001) face of a rger crystal, which is frequent and also seems to occur in more sym- etric pairs. It is very close to Baveno twinning, but, in this associa- ion, the edges (001)/(010) are not parallel, and the edge (110)/(010) of he small plate is parallel, or approximately parallel, to edge (110)/(001) f the larger crystal. A Carlsbad-Baveno equivalent to this association also frequent, also in the form of a small plate on a larger crystal. hese are temporarily termed pseudo-Baveno and pseudo-Carlsbad- aveno associations. These are two cases that might be given as con- irmation of the existence of 'heterozwillinge', for no rational explana- ion of them has yet been found.

The following table gives the number of specimens of the less common ypes, the 'quantitative material' being that collected by Messrs. Montgomery and Over from a single large mass of rock (p. 2).

Relative frequencies of less common laws and groups.

	Quantitative material.	Other material.
Manebach long type	23	13
,, 'capped'	18	9
,, 'short type'	25	7
Baveno long...	16	14
,, short	56	7
Carlsbad with Manebach	16	12
Carlsbad with Manebach, repeated ...	1	—
'Carlsbad-Manebach'	2	—

[1] O. Mügge, Neues Jahrb. Min., 1890, vol. ii, p. 89.

Relative frequencies of less common laws and groups (*cont.*)

	Quantitative material.	Other material.
Complexes of Carlsbad and Manebach:		
c-axes near 156°	2	1
c-axes near 104°	1	2
c-axes tilted near 104°	—	1
c-axes near 76°	—	2
c-axes near 52°	—	2
c-axes tilted near 52°	—	2
Carlsbad with Baveno	18	10
,, ,, repeated	—	1
'Carlsbad-Baveno association'	25	13
Carlsbad with Carlsbad-Baveno	17	6
Manebach with Baveno	2	3
Carlsbad, Manebach, and Baveno ...	2	3
Twins on (110)	28	3
Twins on (130)	6	—
Undetermined cases with parallel *c*-axes ...	3	4
Goodsprings type twins	40	12
Nevada law	17	4
Petschau law	12	7
Twins on X and Y laws	10	9
Miscellaneous, undetermined cases ...	30	21

Conclusions.

Theoretical conclusions have been, as far as possible, excluded from this note. We will therefore consider only the practical results obtained. The difficult nature of the material, even that from this very interesting occurrence, still leaves doubtful and unexplained cases. A few new facts have, however, been obtained and some old doubts cleared up.

Besides the three common twin-laws of orthoclase, the Carlsbad, Baveno, and Manebach laws, the following less frequent ones have been observed:—

Twinning on (110) and on (130); no special names.
,, about axis [1$\bar{1}$0]; the Petschau law.
,, on ($\bar{1}$11); only one specimen.

The existence of the following laws has been shown:—

Twinning about axis [$\bar{1}$12]; the name 'Nevada law' is proposed.
,, on (111); only one specimen.
,, on a (*hkl*) face, measurements of a number of specimens near the theoretical angles for twinning on ($\bar{1}$12); others vary rather widely from the theoretical angles, and the law remains still doubtful. The type is, however, so uniform and typical that we may give it the

name 'Goodsprings type', since a definite name facilitates the discussion of a type or law. The author, however, suggests that, in theoretical discussion of frequent associations, the combined names of the laws be employed, their designation as a definite 'law' being misleading.

The possible existence of two other laws or modes of grouping are suggested by this material, with (*hkl*) twin-planes, temporarily termed the X and Y cases; also two modes of association near the Carlsbad and Carlsbad-Baveno positions that are given temporary names, the 'pseudo-Baveno' and 'pseudo-Carlsbad-Baveno' cases.

An important result, in the author's view, is the interpretation of a number of doubtful cases in the (100)/(001) zone as associations of the Carlsbad and Manebach laws. This interpretation affords an explanation of the following very doubtful 'laws':—

The 'Emfola' law (twinning on ($\bar{4}03$)), twinning on ($\bar{7}.0.11$), (15.0.4), and ($\bar{1}5.0.8$); probably also twinning on (1.10.0) of Haushofer.

The interpretation of Müller's two cases as Carlsbad-Baveno cases renders unnecessary the twin-laws on ($\bar{8}63$), and on the axes [$\bar{4}30$] and [$\bar{1}30$].

The wide variation in the angles of cases with (*hkl*) twin-planes also points to the improbability of such laws as twinning on (661) and ($\bar{2}.5.15$) brought forward by K. Haushofer,[1] though measurements on adularia may give better readings than those on orthoclase.

Laws for which the Goodsprings material has brought no new data are twinning on ($\bar{2}01$) and on ($\bar{1}02$). Material from other localities is in support of twinning on ($\bar{2}01$); the other law is possible, but so near to Carlsbad twinning that it seems improbable.

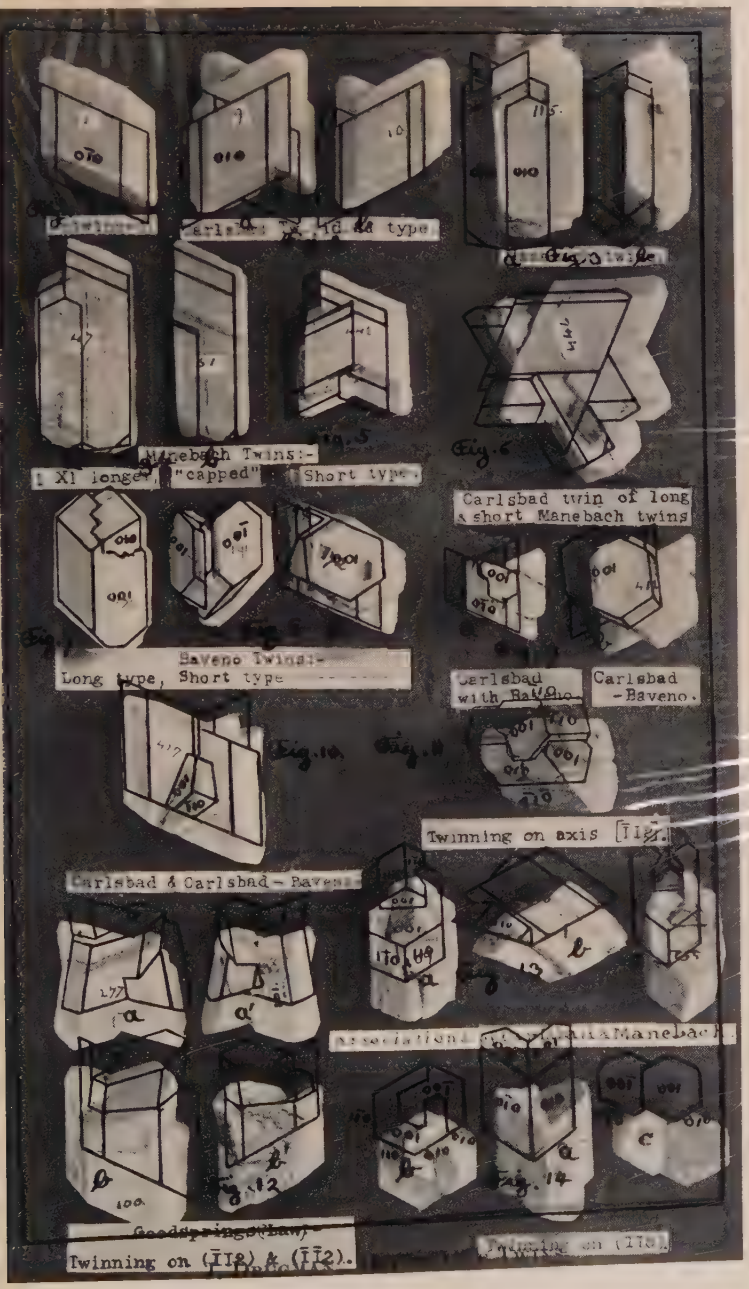
[1] C. Hintze, Handbuch Min., 1897, vol. 2, p. 1342.

Explanation of Plate I.

Crystals of orthoclase from Goodsprings, Nevada. Natural size.

Fig. 1. Untwinned crystal of normal Goodsprings habit.
Fig. 2. Carlsbad twins: (*a*) normal type; (*b*) unsymmetric type.
Fig. 3. Long type Manebach twins: (*a*) with blunt lower end; (*b*) with acute lower end.
Fig. 4. Abnormal development of Manebach twin: (*a*) one crystal longer; (*b*) 'capped' variety.
Fig. 5. Short type Manebach twin.
Fig. 6. Long and short types of Manebach twins associated in Carlsbad twinning.
Fig. 7. Normal type Baveno twin.
Fig. 8. (*a*) and (*b*) short type Baveno twins.
Fig. 9. (*a*) Carlsbad with Baveno; (*b*) 'Carlsbad-Baveno association'.
Fig. 10. Carlsbad with Carlsbad-Baveno.
Fig. 11. 'Nevada law' twin; twin-axis the edge (110)/($1\bar{1}1$). (The twin-axis is in the plane of the drawing and horizontal.)
Fig. 12. (*a*) and (*b*), (*a'*) and (*b'*). Goodsprings type, right and left.
Fig. 13. (*a*) and (*b*) 'Manebach-Carlsbad-Manebach association'. (*c*) 'Carlsbad-Manebach-Carlsbad-Manebach-Carlsbad association'.
Fig. 14. Twins on (110); (*a*) prism-zone vertical, in plane of drawing; (*b*) and (*c*) prism-zone normal to plane of drawing.

MIN. MAG., vol. xxv. *Plate 1.*



J. DRUGMAN: ORTHOCLASE TWINS

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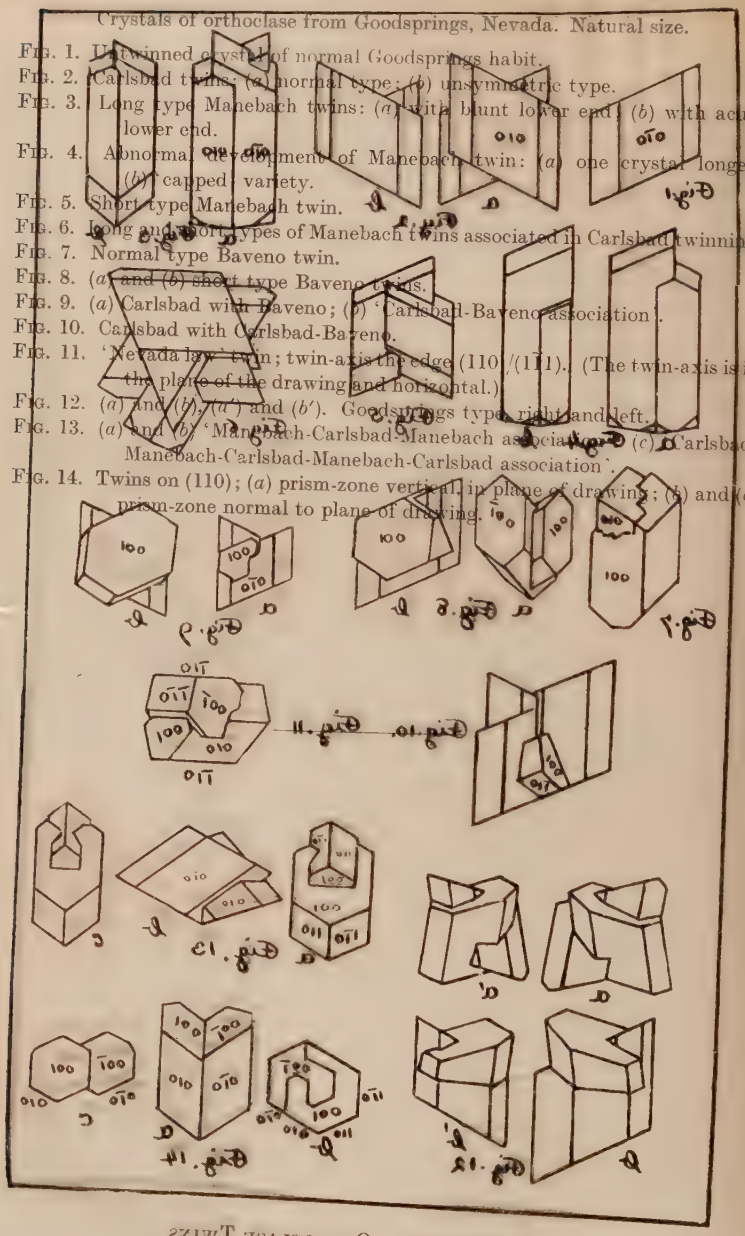

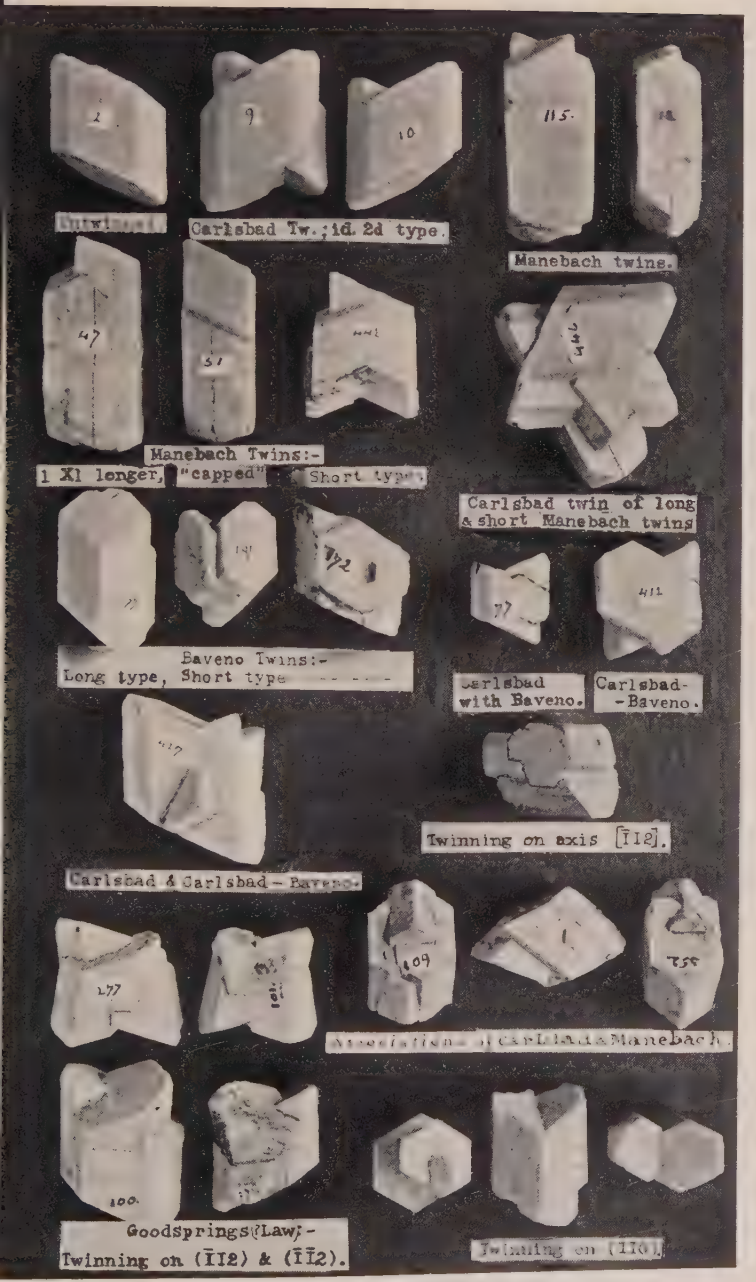

J. DRUGMAN: ORTHOCLASE TWINS

Two new pyroxenes included in the system clinoenstatite, clinoferrosilite, diopside, and hedenbergite.

By W. A. Deer, M.Sc., Ph.D.
Department of Geology, University of Manchester,
and L. R. Wager, M.A., B.Sc., F.G.S.
Department of Geology, University of Reading.

[Read June 24, 1937.]

TWO monoclinic pyroxenes from the Skaergaard Halvoen intrusion,[1] Kangerdlugssuak, East Greenland, have been separated and analysed. They occur in a strongly differentiated gabbro complex which ranges from a hypersthene-olivine-gabbro at the base to a fayalite-quartz-gabbro of unique composition at the top. The differentiation has proceeded with a steady increase in iron and a corresponding decrease in magnesia, while the other major oxides remain relatively constant throughout. The clinopyroxenes in the lower horizons are in equilibrium with labradorite, normal olivine and hypersthene, and are fairly normal varieties as shown by the following optical properties:—

(1)...α 1·672, β 1·678, γ 1·701, 2V 42°, $\gamma : c$ 39°, sp. gr. 3·34.
(2)...α 1·695, β 1·702, γ 1·722, 2V 43°, $\gamma : c$ 41°, sp. gr. 3·38.

In ascending to higher horizons both the orthorhombic and monoclinic pyroxenes become progressively richer in the ferrosilite molecule; in the later differentiates hypersthene ceased to form as a separate phase. The analyses and optical properties of two pyroxenes from rocks high in the series where orthorhombic pyroxene is absent are presented here (tables I and II). As will be seen these pyroxenes are low in sesquioxides, and it is possible as a first approximation to regard them as members of the system wollastonite, clinoenstatite, and clinoferrosilite.

Pyroxene I occurs in one of the earlier rocks of the differentiation series which contains no hypersthene. It is titaniferous and is of special interest in that the aluminium is insufficient to bring the value of the

[1] L. R. Wager, Geological investigations in East Greenland, Part I. Meddel. om Grønland, 1934, vol. 105, no. 2, pp. 36–37.

TABLE I. Analyses and optical data[1] of pyroxenes. (Analyst, W. A. Deer.)

	I.	II.		I.	II.
SiO_2 ...	42·32	42·62	2V (positive)	44°	58°
TiO_2 ...	4·42	1·69	$\gamma:c$	39°	47°
Al_2O_3 ...	2·25	5·24	Refr. indices α	1·721	1·743
Fe_2O_3 ...	4·72	3·74	Refr. indices β	1·728	1·751
FeO ...	25·13	31·54	Refr. indices γ	1·749	1·772
MnO ...	0·22	0·78	Pleochroism α	yellow-brown	pale-green
MgO ...	8·33	0·47	Pleochroism β	violet-brown	green
CaO ...	12·07	12·27	Pleochroism γ	violet-brown	green
Na_2O ...	0·61	1·02	Dispersion	$r > v$	$r > v$
K_2O ...	trace	0·23			
H_2O+ ...	0·12	0·48			
H_2O- ...	0·25	0·22			
	100·44	100·30	Weight%[2] Wo.	27·2	30·0
Sp. gr.[3] ...	3·50	3·65	Weight%[2] En.	22·5	1·5
			Weight%[2] Fe.	50·3	68·5

I. Pyroxene from hortonolite-quartz-gabbro (E. G. 1907).

II. Pyroxene from fayalite-quartz-gabbro (E. G. 1881).

TABLE II. Calculation of formulae of pyroxenes I and II.

	Mol. ratios.	No. of metal atoms on basis of 6(O,OH).		Mol. ratios.	No. of metal atoms on basis of 6(O,OH).		
	I.			II.			
SiO_2 ...	0·7046	1·720		0·7096	1·785		2·00
Al_2O_3 ...	0·0220	0·107	1·96	0·0513	0·258	0·215	
						0·043	
TiO_2 ...	0·0552	0·135		0·0211	0·053		2·02
Fe_2O_3 ...	0·0296	0·144		0·0234	0·118		
FeO ...	0·3497	0·853		0·4390	1·105		
MnO ...	0·0031	0·008		0·0110	0·028		
MgO ...	0·2066	0·503	2·08	0·0117	0·029		
CaO ...	0·2152	0·525		0·2188	0·550		
Na_2O ...	0·0098	0·048		0·0164	0·083		
K_2O ...	—	—		0·0024	0·012		

I. $(Mg,Fe'',Fe''',Ca,Mn,Na)_{2\cdot1}\,[(Si,Al,Ti)_2O_6]$.

II. $(Mg,Fe'',Fe''',Ca,Mn,Na,K,Ti,Al)_2[(Si,Al)_2O_6]$.

[1] Determinations of 2V and $\gamma:c$ ($\pm 2°$) were made on the universal stage. We wish to thank Mr. N. F. M. Henry for confirming certain of these determinations. Refractive indices $\pm$ 0·002.

[2] Disregarding sesquioxides, titania, and alkalis.

[3] Determined by matching in Clerici solution and measuring density of solution with a hydrostatic balance.

Si,Al) group to 2. Machatschki[1] suggested as the general monoclinic yroxene formula: $XY(Si,Al)_2(O,OH,F)_6$, in which X = Ca, Na, (K), Mn), (Mg), and Y = Mg, Fe, Mn, Al, (Zn), (Ti). Although this formula ppears to be applicable to many augite analyses,[2] it fails to satisfy a umber of titaniferous pyroxenes when these are low in sesquioxides, pecially alumina. This point was made by Dixon and Kennedy,[3] who sted a number of titaniferous pyroxenes in which the combined silicon nd aluminium is insufficient to satisfy the silicon chains of the pyroxene ructure. There seems to be no way out of the assumption that silicon ay be replaced by titanium in spite of the difference in size of the ionic dii, and in the co-ordination numbers of the two quadrivalent cations. his question has been discussed by Barth in connexion with the titani-rous augite from Hiva Oa, Marquesas Islands,[4] and, although he cal-lates the analysis into the constituent molecules, he concludes that Ti^{++++} as well as Al^{+++} may replace Si^{++++} in the pyroxene structure. he analysis, optical properties, and calculation of the Hiva Oa pyroxene the basis of six oxygens to the unit cell are given below (table III) for mparison with the pyroxene from Kangerdlugssuak. Barth has also

TABLE III. Pyroxene from Hiva Oa, Pacific Ocean. (T. F. W. Barth, 1931.)

	Wt. %	Mol. ratios.	No. of metal atoms on basis of 6(O,OH).	
SiO_2	47·11	0·7843	1·754	
TiO_2	3·75	0·0469	0·105	1·99
Al_2O_3	3·00	0·0294	0·132	
Fe_2O_3	3·84	0·0240	0·107	
FeO	12·20	0·1698	0·380	
MgO	16·65	0·4105	0·918	1·96
CaO	13·54	0·2414	0·540	
Na_2O	0·22	0·0355	0·016	
K_2O	0·03	0·0032	0·002	
	100·34			

$(Mg,Fe'',Fe''',Ca,Na)_2[(Si,Al,Ti)_2O_6]$.

Sp. gr. 3·32, α 1·695, β 1·701, γ 1·728, 2V 46°, $\gamma:c = 39°$.

[1] F. Machatschki, Über die Formel der monoklinen Amphibole und Pyroxene. its. Krist., 1929, vol. 71, pp. 219–236. [M.A. 4–202.]

[2] B. E. Warren and J. Biscoe, The crystal structure of the monoclinic pyroxenes. its. Krist., 1931, vol. 80, pp. 391–401. [M.A. 5–186.]

[3] B. E. Dixon and W. Q. Kennedy, Optically uniaxial titanaugite from Aberdeen-ire. Zeits. Krist., 1933, vol. 86, pp. 112–120. [M.A. 5–440.]

[4] T. F. W. Barth, Pyroxen von Hiva Oa, Marquesas-Iseln und die Formel anhaltiger Augite. Neues Jahrb. Min., Abt. A, 1931, Beil.-Bd. 64, pp. 217–224. .A. 5–219.]

demonstrated experimentally that diopside is capable of incorporating 10% $CaMgTi_2O_6$ without destroying the essential structure of the pyroxenes. Machatschki's[1] suggestion that titanium may replace silicon at high temperatures and that crystals so formed would be metastable at ordinary temperatures does not appear to be valid in the case of the Kangerdlugssuak pyroxene I. This pyroxene is very rich in ferrous iron, an unusual condition in titaniferous pyroxenes; all titaniferous augites quoted by Doelter[2] are low in iron, and most of the later analyses confirm this observation. It has crystallized in stable equilibrium with the other phases under conditions of slow cooling, and since the magma is rich in iron the temperature of the crystallization was probably low. On the basis of six (O,OH,F) atoms to the unit cell it is necessary to assume, if the pyroxene structure is to be maintained, that the whole of the titanium in the Kangerdlugssuak pyroxene is replacing silicon, and Machatschki's formula must be modified to: $XY(Si,Al,Ti)_2(O,OH,F)_6$ for titaniferous pyroxenes in which TiO_2 is greater than Al_2O_3. Kunitz[3] has recently discussed the role of titanium in garnets and came to the conclusion that Ti may replace Si in those garnets containing an appreciable amount of titanium.

Pyroxene II is an almost pure member of the hedenbergite-clinoferrosilite solid solution series prepared by Bowen, Schairer, and Posnjak,[4] and it has almost identical refractive indices: for the natural pyroxene α 1·743, γ 1·772; and for the artificial melt pyroxene containing 70% $FeSiO_3$ and 30% $CaSiO_3$ α 1·744, γ 1·772. Although occurring in the gabbro in patches of approximately the same size and shape as the other Kangerdlugssuak pyroxenes these patches consist of variously orientated grains, a feature which is also well displayed in other rocks of about the same position in the differentiation series. This texture is a clear indication that the pyroxene has formed by inversion from some other mineral. The work of Bowen, Schairer, and Posnjak on the system CaO–FeO–SiO_2 suggests that the higher-temperature mineral was a β-wollastonite solid solution. Tilley[5] has recently shown that an iron-bearing wollastonite with probably about 25 wt. % of $FeSiO_3$ is present in the hybrid zone at Scawt Hill, whereas the more iron-rich wollastonite solid solution, which was presumably the high-temperature

[1] F. Machatschki, Centr. Min., Abt. A, 1930, p. 192.

[2] C. Doelter, Handbuch der Mineralchemie. 1914, vol. 2, p. 559, nos. 132–137.

[3] Kunitz, Neues Jahrb. Min., Abt. A, 1936, Beil.-Bd. 70, p. 395. [M.A. 7–30.]

[4] N. L. Bowen, J. F. Schairer, and E. Posnjak, The system CaO–FeO–SiO_2. Amer. Journ. Sci., 1933, ser. 5, vol. 26, pp. 193–284. [M.A. 5–454.]

[5] C. E. Tilley, Min. Mag., 1937, vol. 24, pp. 569–572.

rm of the Kangerdlugssuak pyroxene II, has inverted to a heden-rgite solid solution. The melt work of Bowen and his collaborators d suggested (loc. cit., pp. 217–221, 260–261) that such contrasted haviour would probably occur in nature.

The titaniferous pyroxene from the hortonolite-quartz-gabbro and ferriferous pyroxene from the fayalite-quartz-gabbro are both of nsiderable interest as they represent an extension of the field of turally occurring pyroxenes. Winchell[1] recently stated that the ximum tenor of iron in pyroxenes could be expressed by the formula $CaFeSi_2O_6$, and that under ordinary magmatic conditions mixed crys-s of the system clinoenstatite, clinoferrosilite, and diopside, with more n about 50 % $FeSiO_3$ would not be formed. Bowen (loc. cit., p. 198) s shown experimentally that a much higher tenor of iron is possible pyroxenes of artificial melts. Thus in the system hedenbergite–rosilite a pyroxene containing as much as 80 % $FeSiO_3$ has been tained, and in the system $MgSiO_3$–$FeSiO_3$ a pyroxene with 87 % of SiO_3. The two natural iron-rich pyroxenes I and II from Kangerd-ssuak contain 50 % and nearly 70 % $FeSiO_3$ respectively.

Tomita[2] in 1934 drew up a valuable series of diagrams showing the ationship between composition and optical properties in the clino-statite–clinohypersthene–diopside–hedenbergite system. Since then ther data have been obtained which justify revision of the diagram the α and γ refractive indices. The new diagrams, figs. 1 and 2, are sed on the data used by Tomita, together with Bowen, Schairer, and snjak's optical data (loc. cit., pp. 259–261) on the synthetic clino-statite–clinohypersthene series, Bowen's determinations on natural noferrosilite,[3] our determinations on the Kangerdlugssuak pyroxenes, l the data collected in table IV. The two analysed augites C and D ble IV) are complexly zoned and not ideally suited for plotting on the grams as their properties are variable, but in each case the lowest lues for α and γ have been used, these fitting moderately well with the ner data. The revised diagrams (figs. 1 and 2) show the greatest ount of change from the middle of the field diopside, hedenbergite noferrosilite, clinoenstatite, towards the ferrosilite component. The

[1] A. N. Winchell, Further studies in the pyroxene group. Amer. Min., 1935, . 20, p. 566. [M.A. 6–294.]

[2] T. Tomita, Variations in optical properties, according to chemical composition, the pyroxenes of the clinoenstatite-clinohypersthene-diopside-hedenbergite tem. Journ. Shanghai Sci. Inst., Sect. 2., 1934, vol. 1, pp. 41–58. [M.A. 6–71.]

[3] N. L. Bowen, Ferrosilite as a natural mineral. Amer. Journ. Sci., 1935, ser. 5 . 30, pp. 481–494. [M.A. 6–260.]

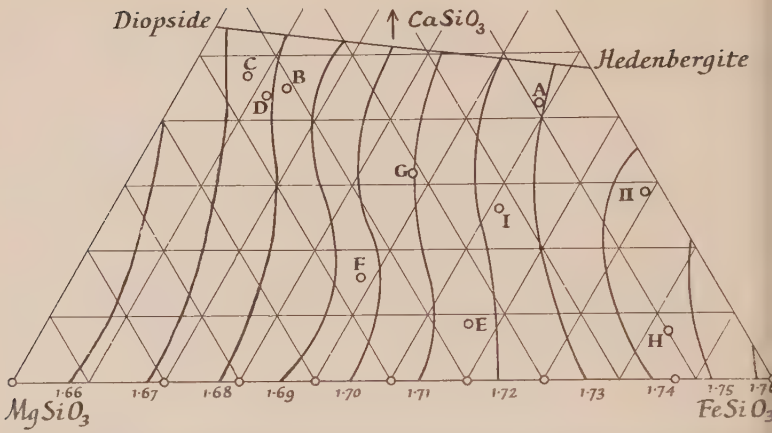

FIG. 1. Variation in chemical composition and the refractive index α in the system diopside, hedenbergite, clinoenstatite, and clinoferrosilite. The Roman numerals refer to the analyses of the Kangerdlugssuak pyroxenes (table I); A, B, C, and D to the pyroxene analyses on page 21; E to pigeonite from Mull, Scotland (A. F. Hallimond, Min. Mag., 1914, vol. 17, p. 97); F to pigeonite, Åland Islands, Finland (W. Wahl, Min. Petr. Mitt. (Tschermak), 1907, vol. 26, p. 18); G to pigeonite, Lake Onega, Russia (W. Wahl, ibid., p. 27); H to artificial mineral from a slag (N. L. Bowen, Journ. Washington Acad. Sci., 1933, vol. 23, p. 83 [M.A. 5–454].

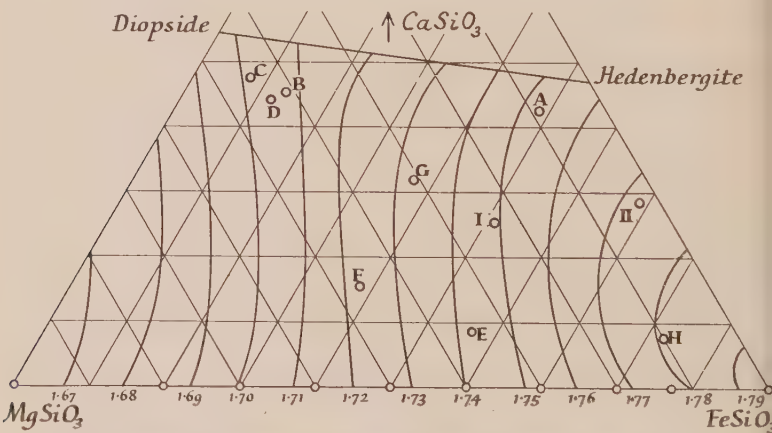

FIG. 2. Variation in chemical composition and in the refractive index γ in the system diopside, hedenbergite, clinoenstatite, and clinoferrosilite. For meaning of the letters and numbers see fig. 1.

w values for the refractive indices of the clinoenstatite–clinohypers-ene series have made the curves for both α and γ much flatter than ose given by Tomita.

TABLE IV. Pyroxene analyses and optical data.

	A.	B.	C.	D.
O_2 ...	47·58	50·40	49·86	50·10
O_2 ...	0·37	1·13	0·41	0·70
O_3 ...	1·16	1·63	5·48	4·57
$_2O_3$ ...	2·60	2·06	2·42	2·34
O ...	24·21	9·74	4·23	7·14
nO ...	0·59	0·09	0·15	0·32
gO ...	3·34	13·37	15·02	14·20
aO ...	18·80	20·65	22·34	20·18
$_2O$ ...	0·47	0·66	nil	0·32
O ...	0·21	0·23	nil	trace
O+ ...	0·34	0·48	0·20	0·24
O− ...		0·03	0·11	0·10
	99·67	100·47	100·22	100·21
...	42·5	45·2	47·8	44·0
...	9·1	41·3	45·0	43·3
...	48·4	13·5	7·2	12·7
... ...	1·730	1·691	1·680–1·698	1·684–1·700
.. ...	1·736	1·697	1·687–1·704	1·692–1·708
.. ...	1·755	1·718	1·706–1·723	1·707–1·721
...	60°	51–66°	58°2′–59°9′	50°41′–57°55′
...	45°	43°	43–44°	41–43°

Hedenbergite from Percy quadrangle, New Hampshire. R. W. Chapman and C. R. Williams, Evolution of the White Mountain magma series. Amer. Min., 1935, vol. 20, p. 512. [M.A. **6**–215.] (Analyst, F. A. Gonyer.)

Phenocryst in pumice, Komagataké, Japan. (Calculated analysis from mixed analysis of pyroxene and hypersthene, and analysis of the hypersthene.) S. Kôzu, The great activity of Komagataké in 1929. Min. Petr. Mitt. (Tschermak), 1934, vol. 45, pp. 133–174. [M.A. **6**–21.]

Augite from Wadaki, Idu, Japan. H. Kuno and M. Sawatari, On the augites from Wadaki, Idu, and from Yoneyama, Etigo, Japan. Japanese Journ. Geol. Geogr., 1934, vol. 11, pp. 327–343. [M.A. **6**–19.] (Analyst, S. Tanaka.)

Augite from Yoneyama, Etigo, Japan. Ibid. (Analyst, S. Tanaka.)

Tomita's diagram showing the variations of the optical axial angle d the extinction-angle $\gamma:c$ is given here unchanged except for the ldition of circles marking the position of the newly analysed pyroxenes g. 3). It will be seen that the diagram does not fit at all closely the lues of 2V and $\gamma:c$ which have been found for the Kangerdlugssuak

pyroxenes. The discrepancies will probably be found to be due to the fact that these values, unlike the refractive indices, are very sensitive to variations in the amounts of the other constituents occurring in natural pyroxenes.

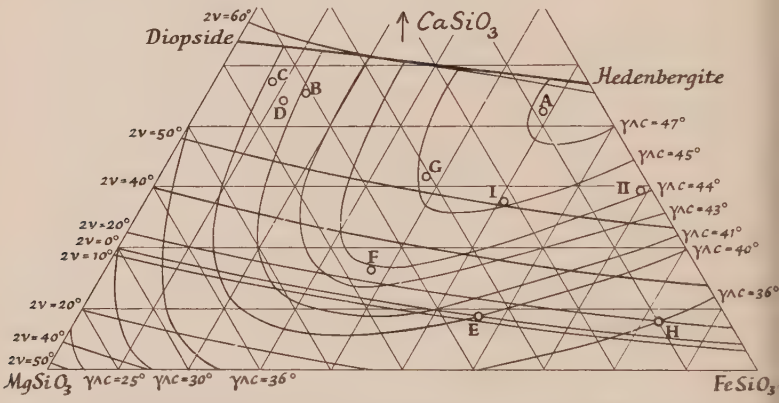

FIG. 3. Variation in chemical composition and in the values 2V and $\gamma:c$ in the system diopside, hedenbergite, clinoenstatite, and clinoferrosilite (after T. Tomita, 1934).

The rocks containing the analysed pyroxenes from the Skaergaard Halvoen gabbro complex will be described in a later paper and the petrological significance of the iron-rich rocks and pyroxenes discussed.

A review of the data of the Mg-Fe-clinopyroxenes.

By N. F. M. Henry, M.A., B.Sc.

Department of Mineralogy and Petrology, University of Cambridge.

[Read June 24, 1937.]

IN recent years several occurrences of clinoenstatite and of clinohypersthene have been recorded, the identification depending on the oblique extinctions measured from a prominent cleavage. This is, of course, quite inconclusive, because many sections of hypersthene show extinction-directions oblique to the trace of a prominent cleavage, and much fuller data would be necessary before most of these occurrences could be accepted as monoclinic Mg-Fe-pyroxenes.

The terms clinoenstatite and clinohypersthene appeared for the first time in 1906 when both W. Wahl and A. Lacroix introduced them for the monoclinic Mg-Fe-pyroxenes which had been often observed in meteorites. Lacroix mentioned several meteorites in which these minerals were reported to have been present, while in his 'Minéralogie de la France' (1910) he noted the French occurrences. The only data given, apart from those on artificial products, are the constant lamellar structure parallel to (100) and the maximum extinction-angle of 22–29°, while the division between clinoenstatite and clinohypersthene was made at 10 % FeO to correspond with the division in the orthorhombic series. Michel (1913) found these minerals in many kinds of meteorites.

J. Ebelmen in 1851 was the first to produce $MgSiO_3$ artificially, but the monoclinic nature of his product was not recognized until 1881 when F. Fouqué and A. Michel-Lévy investigated the artificial production of minerals. In their book they give references to the other early workers who had produced this mineral without realizing that it was monoclinic. In 1906 A. Lacroix obtained the monoclinic form through inversion of the orthorhombic by heating the latter near its temperature of fusion. In this same year the Geophysical Laboratory at Washington began its thermal study of artificial melts with a paper on minerals of the composition $MgSiO_3$ by E. T. Allen, F. E. Wright, and J. K. Clement (1906). This paper and most of the subsequent ones give optical data on the various minerals produced, but a new form α-$MgSiO_3$ noted by E. T. Allen and W. P. White (1909) was shown later by N. L. Bowen and

O. Andersen (1914) to be really forsterite. The papers of N. L. Bowen (1914) and O. Andersen (1915) give later data on the pure clinoenstatite produced by them. In more recent years, the study of systems containing CaO, MgO, FeO, and SiO_2 has greatly extended our knowledge of the Mg-Fe-clinopyroxene series and the relationships of the various phases are now well known (see N. L. Bowen and J. F. Schairer, 1932 and 1935; N. L. Bowen, J. F. Schairer, and E. Posnjak, 1933). The name 'ferrosilite' suggested by Washington has been adopted by N. L. Bowen (1935) for the $FeSiO_3$ molecule.

Very little structural work has been done on this series of minerals. In 1925 R. W. G. Wyckoff, H. E. Merwin, and H. S. Washington took powder photographs of several different pyroxenes and they state (p. 385) that clinoenstatite gives a diffraction-pattern which is, apparently, unlike that of any of the other pyroxenes examined. This statement, however, seems to refer to artificially produced clinoenstatite obtained by inverting enstatite from Espedalen at 1400° C. and the authors admit that this is unlikely to produce a pattern exactly similar to that of pure clinoenstatite. B. E. Warren and J. Biscoe (1931) took oscillation photographs of this mineral which showed the same pattern as those of diopside, but they did not state the nature of the actual material used. In 1935 N. L. Bowen and J. F. Schairer used powder photographs in identifying their artificial products. None of these papers give any reproductions of X-ray photographs of the minerals of this series.

In the case of terrestrial rocks, with the exception of the practically pure clinoferrosilite described by N. L. Bowen (1935) from the lithophysae of an obsidian from Naivasha, Kenya, the identification of all the reported occurrences examined rests on insufficient data. S. Tsuboi (1920, p. 83) reports clinohypersthene in a lava as having the same optical properties as the hypersthene which accompanies it, except that in the former the optic axial plane is transverse to the *c*-axis. In view of the fact that all known clinoenstatites and clinohypersthenes are optically positive and have the optic axial plane more nearly parallel than perpendicular to the *c*-axis, and that the maximum optic axial angle reported for them is equal to the minimum reported for the hypersthenes, it is obvious that much more data are required before this Japanese occurrence could be accepted as belonging to the series of minerals under discussion, especially as the characteristic polysynthetic twinning is absent in this case. J. Gotthard (1928) also reports an occurrence in a melaphyre of a clinohypersthene, similar to the hypers-

hene which accompanies it, except that it shows extinction-angles up o 10°. Clinoenstatite showing extinction-angles up to 30° was reported y A. Holmes and H. F. Harwood (1932) as cores of zoned enstatite in apilli in a melilite-basalt from Uganda. Clinoenstatite is said by E. O. eale (1928) to occur in a diamondiferous kimberlite pipe in Tanganyika, ut no data are given, while P. A. Wagner (1925) describes poly-ynthetically twinned clinobronzite in a platinum-bearing norite on the rounds of a maximum extinction-angle of 3° 15′ in the symmetrical one.

In describing the Johnstown meteorite, E. O. Hovey (1925) gives ome data and an analysis of a sample of monoclinic pyroxenes which e calls clinohypersthene on the grounds of extinction-angles of about -15° and a lamellar structure, which he describes as 'polysynthetic winning on the clinopinacoid (010)'. But this mineral is optically egative and its other properties agree with those of hypersthene, so he lamellar structure is probably that which is often seen in ortho-hombic pyroxenes although as yet unexplained. The 'clinohypersthene' eported by H. Service (1934) has since been identified as hypersthene, he inclined extinctions and lamellar appearance having led to the istake.[1] In his description of the geology of Dôgo in the Japan Sea, . Tomita (1936) gives some data on a mineral which he suggests is a linohypersthene of very low optic axial angle and for which he proposes he name 'gokaite'. The low 2V suggests the presence of some CaO, ut the mineral is optically negative, while all the identified occurrences f this series and of the pigeonites are optically positive. Until further ata are available it is impossible to include this 'gokaite' in the mineral eries under discussion. M. S. Krishnan (1936) has suggested the pre-ence of clinoenstatite in a meteorite along with enstatite on the basis f oblique extinction alone, while a reported occurrence in an igneous ock with more data (J. Verhoogen, 1937) is discussed below. In each f these cases the inclined extinctions are no proof of monoclinic sym-metry, while a lamellar structure is quite common in orthorhombic yroxenes.

In the case reported by J. Verhoogen (1937) from a lava the mineral n question is often zoned and the maximum extinction-angles rise from ° in the cores to 16° or 18° on the outside. The data given for the ypersthenes are rather vague, but in the same section crystals with V 90° and 55° occur. The author thinks that these extinctions cannot e explained by the obliquity of the section if the mineral were ortho-

[1] Personal communication from Mr. Service.

rhombic; but calculation shows that, for example, in a section inclined at 15° from the prism-zone and at 15° from normality to the optic axial plane the extinction-angle from the slow ray to the trace of *c* would be $5\frac{1}{2}°$ where $2V_\alpha = 80°$, and 16° where $2V_\alpha = 50°$. Extinction-angles might well be measured on such a section, and the data are consistent with an orthorhombic pyroxene becoming markedly enriched in iron during crystallization, which explains the rise in refractive index outwards from the core, while the accompanying decrease of 2V over α accounts for the increase noticed in the extinction-angles on these oblique sections. The statement made that changes in pleochroism, colour, and birefringence are not related to change in extinction-angle is quite understandable, for, especially in sections showing low birefringence, which are those with the largest extinction-angles, the increase in birefringence would be hardly noticeable, while pleochroism is not connected with increase in iron.

The conclusion can, therefore, be drawn that no example of monoclinic Mg-Fe-pyroxene has been proved to occur in terrestrial rocks, except that of the iron end-member, clinoferrosilite, which itself may have been metastable and of which the occurrence is unusual. There is a possibility that members of this series may occur as fine intergrowths with other pyroxenes, but this has not yet been thoroughly studied.

In the supplementary volume of Hintze's 'Handbuch der Mineralogie' (1936) crystallographic data on clinoenstatite according to various authors are given; but as no reference is made there to the recent work of N. L. Bowen and J. F. Schairer (1935) and of N. L. Bowen (1935), the available optical data are indicated below. Contradictory statements have been made about the properties of members of this series, but it is now possible to discard some of these and to lay the basis of a table of optical properties which, however, requires much more data. The diagrams of A. N. Winchell (1935) and of T. Tomita (1934), of which the series under discussion forms a part, show the effects of an increase of lime. The optic axial plane for this series is perpendicular to (010), but beyond the value $2V = 0°$, with increasing lime, it is parallel to (010). Up to the present, no division has been made between the $MgSiO_3$–$FeSiO_3$ series and the pigeonites, both of which are optically positive, and T. Barth (1931) uses the terms 'clinoenstatite' and 'pigeonite' indiscriminately, while G. T. Prior (1920) proposed to extend the former term to cover the pigeonites on the grounds that 'clinoenstatite' has essentially the same meaning as has 'enstatite-augite'. Where lime is appreciable he proposed the term 'calc-clinoenstatite'. But, in view

of our present knowledge, it is desirable to keep the terms 'clinoenstatite', 'clinohypersthene', and 'clinoferrosilite' quite separate from 'pigeonite' or 'enstatite-augite'.

Very few reliable analyses are available of these minerals, but the figure (fig. 1) shows that at present there is a gap between the pigeonites and the series of Mg-Fe-clinopyroxenes which have been prepared artificially and which are said to be common in meteorites, although

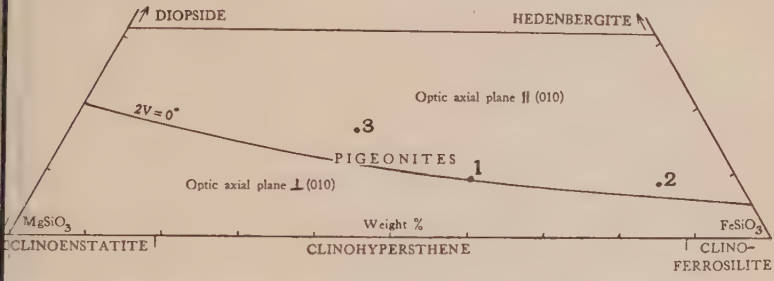

FIG. 1. Diagram showing relationship of the pigeonites to the Mg-Fe-clinopyroxenes.

Analysed pigeonites: 1, Mull (A. F. Hallimond, 1914); 2, from slag (N. L. Bowen, 1933); 3, Åland Islands, Finland (W. Wahl, 1906).

none from meteorites has been analysed. Much more reliable and complete data are required for minerals of this composition and this gap may prove to be non-existent, but at present it makes it unnecessary to draw a sharp dividing line between the pigeonites and the minerals of the clinoenstatite-clinoferrosilite series. A mineral which from its properties must lie quite close to this series is the 'pigeonite B' of E. P. Henderson and H. T. Davies (1936) from the Moore County meteorite. Its greater birefringence than the corresponding pure member of the series with the same value of γ shows that it probably contains a little CaO. A few occurrences of pigeonites with the optic axial plane perpendicular to (010) are recorded, but the available data are too scanty to be used in plotting them. T. Barth (1931, pp. 201–202) mentions one from the basalt of Katem quarry, Madras, with 2V 20°. A. Osann (1907, p. 708) describes one from a Tasmanian diabase, and P. D. Quensel (1912, p. 77) one from a Patagonian diabase, both of which have a low optic axial angle and an extinction-angle $\gamma:c$ of 45°, which makes it impossible to plot them on the latest diagrams of A. N. Winchell (1935) or of T. Tomita (1934) recently improved by W. A. Deer and L. R. Wager (1938). W. Wahl (1907, pp. 6, 29, 64, 65, 68, and 90) gives two examples

of this type of orientation, from the diabase of Richmond, South Africa, and from the Juvinas meteorite, but when the old analyses of these are plotted the points lie on the wrong side of the line $2V = 0°$, while a third analysis, from the meteorite of Novo-Urei, lies close to clinoenstatite, but the optic axial plane of the mineral is given as parallel to (010). In view of these discrepancies this point must be left undecided for the present.

N. L. Bowen and J. F. Schairer (1935, p. 199 and fig. 28) give the refractive indices, birefringence, extinction-angle, and optic axial angle of the artificial Mg-Fe-clinopyroxenes prepared by them, while N. L. Bowen (1935) gives data on the naturally occurring clinoferrosilite. In the former paper 2V is given as 20–25° for the whole series, but in the earlier papers of E. T. Allen and W. P. White (1909, p. 30) and of N. L. Bowen (1914, p. 252) 2V for pure clinoenstatite is given as 53°. The whole series is optically positive with positive elongation and the optic axial plane is perpendicular to (010), while polysynthetic twinning on (100) is always present. The specific gravity of pure clinoenstatite is 3·19, but definite data on pleochroism and dispersion are lacking at present.

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A new micro-pyknometric method for the specific gravity of heavy solids; with a note on the accuracy of specific gravity determinations.

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THE determination of the specific gravity of a solid which is only available in small quantity has always been a difficult problem in cases where the suspension method fails, either because the solid is too dense, or because it dissolves in or reacts with the heavy liquids available. It is hoped that the following method will be found a useful addition to the numerous methods which have been proposed from time to time to meet such cases. References to most of these methods are given at the end of the paper. Neither the new method nor any one of the older ones is universally applicable, and the best method for any particular case will depend on many circumstances.

In the new method, a straight capillary tube of silica-glass, 9 cm. in length, 0·5 mm. in bore, and with walls 0·75 mm. thick, closed at one end and as perfectly cylindrical as possible[1] serves as the pyknometer. This is calibrated by determining the weight of bromoform it holds when filled (by the aid of a fine glass capillary tube and a centrifuge) to several different heights; the length of the column of liquid at each filling is determined after weighing, the tube being placed in a beaker of water at room-temperature along with a delicate thermometer for a few minutes to attain a known temperature and then measured with a travelling microscope. The weighings are made on the micro-balance; the pyknometer is never more than half filled with bromoform, when evaporation errors have been shown to be negligible. From these calibration data and the expansion coefficient of bromoform, the weight of bromoform held by the tube at any given temperature and height of filling may be calculated.

[1] In the tubes now in use, the weight of bromoform per 1 cm. of tube does not vary by more than about 0·2 % from part to part of the tube.

The expansion coefficient of bromoform does not appear to have been determined hitherto. A figure of sufficient accuracy for our purpose was obtained by determining the specific gravity of a sample of bromoform at two temperatures, using the silica-glass pyknometer designed by H. V. Ellsworth (1928). From the results, $d_{20\cdot8}^{20\cdot8} = 2\cdot8670$ and $d_{20\cdot8}^{32\cdot4} = 2\cdot8425$ (both not corrected to vacuum), the apparent coefficient of thermal expansion of bromoform in silica-glass is found to be 0·00074 per 1° C.

The use of the calibrated pyknometer in a specific gravity determination closely follows the usual macro-method. The solid, preferably in as coarse (but non-porous) fragments as will enter the tube, is weighed into the pyknometer. This operation is greatly facilitated by the use of a small filling device turned out of 'perspex' resin in the form of a funnel with its apical aperture about 0·3 mm. in diameter and a support for the pyknometer tube.

If the material is in the form of large smooth crystal fragments, it will often be satisfactory to fill with bromoform, using the glass capillary and centrifuge, and then evacuate to remove residual air bubbles (satisfactory results were so obtained with galena); but with a fine powder any attempt at evacuation after addition of the bromoform has always led to ejection of some of the solid. It is therefore necessary when fine powder is used to support the pyknometer in a wide tube which can be evacuated, and introduce the bromoform after thorough evacuation through a capillary tube projecting a short way into the mouth of the pyknometer, while maintaining the vacuum. In either case, the bromoform column should preferably not extend more than 5 mm. beyond the solid.

The pyknometer plus solid is weighed and the length of the bromoform (plus solid) column measured as in the calibration, after bringing to a known temperature. All the data for the calculation of the specific gravity are now available except the specific gravity of the bromoform. This must be determined in the usual way at fairly frequent intervals, as it varies for different samples and for the same sample after exposure to light and air.

The accuracy of the determinations has been found to be reasonably good. As in all other methods of specific gravity determination in which a liquid displacement medium is used, the presence of air bubbles is often one of the most important sources of error. This error may reach several per cent., and it is difficult to suppress entirely; probably most determinations, by this or other methods, suffer to the extent of at least

0·1 %, the values being always low. It is usual in macro-pyknometric determinations to accept the highest value found as the most accurate for this reason, and the same procedure must be followed when the micro-pyknometer is used.

While this source of error, as well as those due to inclusions in the material and the adsorption of air or vapours on the surface of the pyknometer or the material, must be accounted as of unknown magnitude, there are several sources of error, the probable magnitude of which can be approximately calculated.

If the balance weighs to $\pm\delta W$ grams, the effective volume V c.c. of the pyknometer is reproducible to $\pm\delta V$ c.c., and the temperature can be determined to $\pm\delta t°$ C., the probable percentage error introduced by these uncertainties into the determination of the specific gravity S of W grams of a solid, using a displacement liquid of specific gravity σ and coefficient of expansion α is approximately $\pm 100\delta S/S = \pm(\delta W/S + 2\delta W/\sigma + \delta V + \alpha V\delta t)200S/W\%$.

For the new method, assuming an accuracy of weighing $\delta W = 0{\cdot}002$ mg., of temperature 0·1° C., and of measurement of the bromoform column 0·002 cm., the error using 15 mg. of material of specific gravity 4 and with the bromoform meniscus 4 cm. from the closed end of a pyknometer tube holding 7·5 mg. of bromoform per cm. will be $\pm(0{\cdot}03 + 0{\cdot}07 + 0{\cdot}27 + 0{\cdot}04) = \pm 0{\cdot}4$ %. Allowing for the errors of unknown magnitude, an accuracy of 0·5 % should be and is attainable with 5 to 15 mg. of material. It may be noted that the greatest single error in this case is due to errors of measurement of the length of the bromoform column, and is independent of the displacement liquid used.

These figures may be compared with the accuracy attainable in other methods of specific gravity determination. F. V. Syromyatnikov (1935) claims an accuracy of 0·3 % for his micro-pyknometer method, using 40 mg. of a solid of specific gravity 4, and working with an ordinary balance, and a much greater accuracy with a micro-balance. This figure, however, takes account only of the errors of weighing. The volume error of his pyknometer is uncertain, while the temperature error, also uncertain, must be very large since there is no proper control or measurement of the temperature. It is probable that about ± 1 % is a more accurate estimate of the accuracy of this method; the use of a micro-balance would not assist much, since the largest single error is certainly the temperature error.

In one of the most accurate forms of the macro-pyknometric method, that of H. V. Ellsworth (1928), the attainable accuracy, calculated from

ne above formula, using the exceptionally large amount of 12 grams f a solid of specific gravity 4 and bromoform as displacement liquid, aking the volume of the pyknometer as 8 c.c. and the individual errors $W = 0{\cdot}1$ mg., $\delta V = 0{\cdot}2$ c.mm., $\delta t = 0{\cdot}1°$ C., is $\pm(0{\cdot}002+0{\cdot}005+0{\cdot}013$ $-0{\cdot}039) = \pm 0{\cdot}06\%$, the greatest single error being due to the tempera- ure effect. In this case, the error due to air bubbles, of unknown agnitude but probably not less than $0{\cdot}1\%$, is much more serious than ne errors of known magnitude, but when less material is available, the tter may become important. It may be noted that, contrary to a ommon assumption, there is no advantage gained by using a dense isplacement liquid; the liquid chosen should have a low surface tension, w expansion coefficient, and low volatility, but its density is almost nmaterial.

The micro-volumenometer of H. Hauptmann and G. E. R. Schulze 1934), using a gas as displacement fluid, is claimed to have an accuracy f about 1 % for volumes down to 0·01 c.c. This is inadequate for eneral use, but should prove valuable for highly reactive solids.

The accuracy attainable in a specific gravity determination by the ethod of hydrostatic weighing is difficult to assess; with suitably large pecimens it can be very accurate, probably $\pm 0{\cdot}1\%$ or even better. he greatest source of error is usually the surface tension effect, reducing ie accuracy of the weighings. The method has been applied on a semi- nicro scale by P. Wulff and A. Heigl (1931), who claim an accuracy of ·i % with suitable material in portions of 0·5 gram; it would hardly e suitable for much smaller amounts of material.

The attainable accuracy in the suspension method is often higher than n the pyknometric, if the observer has sufficient patience in adjusting he specific gravities of solid and liquid, the density of the liquid is determined with a good pyknometer, and the temperatures are measured vith adequate accuracy. With the Ellsworth pyknometer the specific ravity of the liquid may be measured to an accuracy of about $\pm 0{\cdot}0003$, nd if the temperature of comparison of liquid and solid is measured to ·1° C. and a correction made for temperature changes, an accuracy of $\pm 0{\cdot}003$ may be attained for solids for which a suitable suspension liquid an be found.

Where the use of a float is necessary the accuracy is reduced. If a olid fragment of specific gravity S and weight W, combined with a float f specific gravity s and weight F remains suspended in a liquid of pecific gravity σ, $S = \sigma+(\sigma - s)F/W$. If both σ and s can be deter- nined with an accuracy of $\pm 0{\cdot}003$, and if s is about 2·3 while σ is near

3·3, the error due to the determination of s and σ is $\pm 0{\cdot}003(1 + 2F/W) = \pm 0{\cdot}003\{1+2(S-\sigma)/(\sigma - s)\}$, which for a solid of specific gravity 4·3 is 0·009 or 0·2 %, and for one of specific gravity 7·3 is 0·027 or 0·4 %. If the float and the solid fragment can be weighed on the micro-balance, this accuracy should be approachable, though the method is by no means simple; but if only an ordinary balance is available a further error is introduced due to inaccuracies in the determination of F and W. The attainable accuracy in the suspension method, using a float and the micro-balance, should thus approach that of the new micro-pyknometric method, but the latter is probably the more convenient in practice.

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On the occurrence of acmite in the riebeckite-microgranite of Mynydd Mawr, Caernarvonshire.

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[Read November 4, 1937.]

THE existence of an unidentified mineral in the riebeckite-microgranite of Mynydd Mawr has been known for almost exactly fifty years. It was first noticed by Harker and described by him in the following words:[1] 'The ground-mass [of the microgranite] is a finely granular admixture of quartz and orthoclase, as in an ordinary "microgranite", but containing in addition another mineral which is often identiful. It occurs in minute crystals of acicular or rectangular form, scattered through the ground-mass or included by the other constituents, and having usually a fluxional arrangement agreeing with that of the parallel hornblende and tourmaline streams. The mineral is colourless, or in the larger crystals gives for vibrations parallel to the long axis a faint tint of indigo-blue. The crystals give high polarisation colours and straight, or nearly straight, extinction. They have a high refractive index, which causes them to stand out in relief when viewed by ordinary transmitted light.'

Almost at the same time, Bonney read a paper before the Mineralogical Society on this same microgranite, in which this doubtful mineral is again mentioned:[2] 'In this ground-mass are numerous belonites, often about ·002″ long, almost colourless, but perhaps of a slight yellowish tint. It is difficult to make sure of their extinction angle, but it is certainly small, though sometimes appreciable. As the slide is rotated the mineral becomes of a rather bright golden colour. Probably it is a variety of hornblende.'

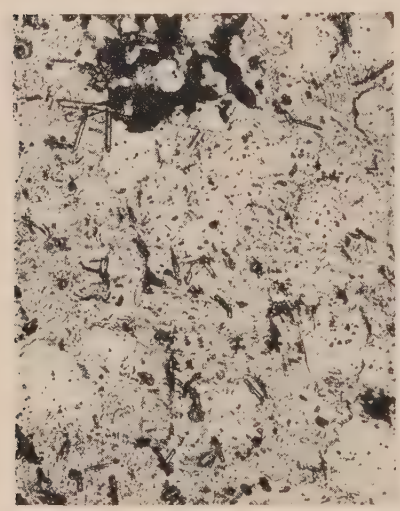
Just as Harker's paper appeared, and Bonney's was read, Sauer[3] described a new member of the amphibole group, riebeckite. In a later paper, Harker points out that the 'hornblende' and 'tourmaline' in the

[1] A. Harker, Geol. Mag., 1888, new ser., dec. 3, vol. 5, p. 225.

[2] T. G. Bonney, Min. Mag., 1888, vol. 8, p. 104.

[3] A. Sauer, Zeits. Deutsch. Geol. Gesell., 1888, vol. 40, 138–146.

Mynydd Mawr rock must be riebeckite. He again refers to the small crystals in the groundmass (loc. cit., p. 456): 'Besides the larger crystals of riebeckite, Sauer finds in the Socotra granite microlites of the same mineral, precisely similar to the colourless and pale-blue microlites already described in the rock of Mynydd Mawr.'



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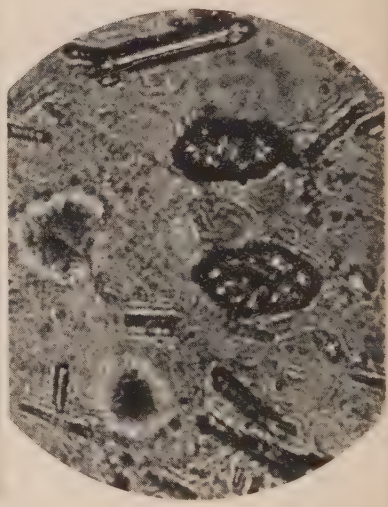

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Fig. 1. Thin section of the Mynydd Mawr microgranite showing some larger and numerous small acicular crystals of acmite. The black mineral is riebeckite. Ordinary light × 100.

Fig. 2. Two basal sections of acmite. The lower one is the better and shows the form (110) with (010) well developed and (100) very poorly developed. The upper one is also flattened on (010). Ordinary light × ca. 530.

It will have been noticed that Harker speaks of these small crystals as being colourless or pale blue, whilst Bonney describes them as almost colourless or having a slight yellowish tint. This is explained by the fact that the small crystals found in the groundmass belong to two different minerals. There are some small pale blue crystals of riebeckite and the greatly preponderating crystals of the unidentified mineral which are colourless or pale yellow. It is with these latter that we are concerned.

These colourless to pale yellow crystals have an average length of some 0·06 mm. Many are very much smaller, whilst some are larger, up to 0·30 mm. in length and 0·06 mm. in breadth. They usually show rather irre ular rounded terminations (fig. 1). Basal sections are

xtremely rare in the thin sections examined, but two are illustrated ig. 2). The form of these basal sections is that of a pyroxene and the rismatic cleavages intersect at an angle of approximately 88°. The rystals show little pleochroism, and twinning on (100) occurs rarely. is just below 1·777, γ a little below 1·843. The optic axial plane is arallel to (010) and the mineral is biaxial negative with a fairly large ptic axial angle. The extinction-angle (α:c) on (010) ranges up to 9°, ut is difficult to determine accurately owing to the high dispersion, ading to incomplete extinction in white light. An attempt was made obtain some measure of this dispersion, using Chance's filters. For ne ruby Chance filter α:c on (010) was 8°, for the violet Chance filter was approximately 10°. The dispersion is therefore $r<v$.

The properties listed above agree with those of acmite. It is already nown that acmite (as distinct from aegirine) may be colourless or ellow in thin section, although this condition does not appear to be ommon.[1]

Two interesting points may be noticed in conclusion. In the first lace, all previously described acmite has been flattened on (100), the rm (010) being either very small or lacking. In the present instance e mineral is flattened on (010) and the form (100) is poorly developed. the second place, the mineral cannot be regarded merely as an ac-ssory constituent. It is quite plentiful in almost all the thin sections xamined, and the microgranite of Mynydd Mawr would be more rrectly described as a riebeckite-acmite-microgranite.

I wish to thank Mr. F. W. Lanham, of the Department of Mineralogy nd Petrology, Cambridge, for taking the photomicrographs which lustrate this paper.

[1] H. S. Washington, Amer. Journ. Sci., 1923, ser. 5, vol. 6, p. 107; H. S. Washing-n and H. E. Merwin, Amer. Min., 1927, vol. 12, p. 233. [M.A. **3**–374, **4**–131.]

On scawtite pseudomorphs after spurrite at Scawt Hill, Co. Antrim.

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[Read November 4, 1937.]

Scawtite was first described at Scawt Hill as a secondary minera occurring in vesicles and venules in melilite of a melilite-rich hybric of the endogenous contact-zone.[1] Since then scawtite has been identified in a gehlenite-vesuvianite-calcite-rock from the contact-zone of a gabbro in the Little Belt Mountains, Montana.[2] The present note records a further occurrence of scawtite at Scawt Hill in a different paragenesis viz. in association with and replacing spurrite of the exogenous contact zone.

In discussing the paragenesis of larnite and spurrite at Scawt Hill, reference was made to the instability of larnite in the presence of calcite the reaction leading to the formation of larnite proceeding in the pre sence of excess calcite to the development of spurrite

$$\underset{\text{(larnite)}}{2Ca_2SiO_4} + CaCO_3 \rightarrow \underset{\text{(spurrite)}}{2Ca_2SiO_4.CaCO_3}.$$

Spurrite is thus a constituent not only of the silicated zone of the contac but also occurs isolated in calcite in the marbles derived from the chalk Spurrite is usually found quite fresh and unaltered in these associations but in a study specially devoted to the secondary minerals of the Scaw Hill locality, a number of examples of spurrite-rocks which have suffered secondary alteration under the influence of late solutions has been encountered. In these, in hand-specimens, the development of scawtite is associated with the appearance of white turbid zones in the clear glassy spurrite associated with calcite.

Under the microscope, the best examples of this pseudomorphou replacement is seen in the spurrite-marbles, where the spurrite occur

[1] C. E. Tilley, Min. Mag., 1930, vol. 22, p. 222.

[2] J. H. Taylor, Amer. Min., 1935, vol. 20, p. 126. [M.A. **6**–125.]

[3] C. E. Tilley and H. F. Harwood, Min. Mag., 1931, vol. 22, p. 445.

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FIG. 1. Melilite-rock, Scawt Hill. Showing melilite with alteration zones and a
n rich in scawite (lath-shaped crystals). × 26 diams.

FIG. 2. The same section between crossed nicols. A subsidiary vein containing
wtite is well seen in this photograph (right-hand side).

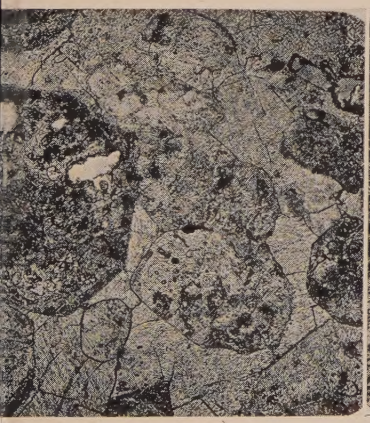

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FIG. 3. Spurrite-marble, Scawt Hill. Idioblastic crystals of spurrite completely
laced by scawtite, set in a ground of calcite. × 30 diams.

FIG. 4. The same section between crossed nicols, showing the aggregate polariza-
n of the scawtite pseudomorphs after spurrite.

as well-shaped idioblasts. All stages from partial to complete replacement can be traced.

The scawtite occurs as fibrous aggregates of radiating, overlapping flakes 0·03 to 0·05 mm. in length, completely replacing spurrite or sometimes with a little interstitial calcite. Larger flakes isolated from the sections show that the mineral is optically positive, 2V high about 75°, α 1·597, β 1·606, γ 1·619, and with a maximum extinction γ to length of fibres 30°. In these properties the mineral agrees with scawtite already described. Additional confirmation is given by micro-chemical tests for carbon dioxide. Inspection of a series of altered spurrite-rocks shows that this scawtite development is the commonest change which spurrite undergoes.

The metasomatic changes involved in the conversion of spurrite to scawtite can be estimated from the known specific gravities of the two minerals. Assuming a replacement without alteration of volume as the pseudomorphs indicate, the chemical changes involve loss of lime and the incoming of silica and carbon dioxide. These changes doubtless operated during the hydrothermal stages in the cooling of the contact-zone. It seems not unlikely that examination of other spurrite occurrences may reveal a similar development of scawtite now discussed.